

VERIFICATION OF TRANSLATION

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802-8691 Japan, do hereby declare that I am familiar with the English language and  
Japanese language, and that the attached document in the English language is a full and  
faithful translation of the Japanese patent application no. 2003-349911.

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[DOCUMENT NAME] CLAIMS 1

[DOCUMENT NAME] DESCRIPTION 1

[DOCUMENT NAME] DRAWING 1

[DOCUMENT NAME] ABSTRACT 1

## [DOCUMENT NAME] CLAIMS

### [Claim 1]

A method of fullerene separation comprising the steps of:

bringing a fullerene mixture into contact with an amine A in a solvent to form a complex of a specific fullerene contained in the fullerene mixture with the amine A, the fullerene mixture comprising any two or more of C60, C70 and higher fullerenes having 70 or more carbon atoms, the amine A having two or more nitrogen atoms; and

separating the complex from a solution in which fullerenes not forming the complex are dissolved.

### [Claim 2]

The method of fullerene separation according to claim 1, wherein the complex is insoluble in the solvent.

### [Claim 3]

The method of fullerene separation according to claim 1 or 2, wherein the complex is dissociated into the specific fullerene and the amine A to obtain the specific fullerene.

### [Claim 4]

The method of fullerene separation according to claim 3, wherein the dissociation of the complex is carried out by bringing the complex into contact with an acid.

### [Claim 5]

A method of fullerene separation comprising:

a first process of bringing a fullerene mixture comprising C60, C70 and higher fullerenes having 70 or more carbon atoms into contact with an amine B having two or more nitrogen atoms in a solvent to generate a first complex formed by the higher fullerenes and the amine B;

a second process of separating the first complex from a first solution in which the C60 and the C70 are dissolved;

a third process of bringing the first solution into contact with an amine C having two or more nitrogen atoms to obtain a second complex formed by the C70 and the amine C; and

a fourth process of separating the second complex from a second solution in which the C60 is dissolved.

[Claim 6]

The method of fullerene separation according to claim 5, wherein the first and the second complexes are insoluble in the solvent.

[Claim 7]

The method for fullerene separation according to claim 5 or 6, wherein the first complex is dissociated into the higher fullerenes and the amine B to obtain the higher fullerenes.

[Claim 8]

The method of fullerene separation according to claim 7, wherein the dissociation of the first complex is carried out by bringing the first complex into contact with an acid.

[Claim 9]

The method of fullerene separation according to any one of claims 5 to 8, wherein the second complex is dissociated into the C70 and the amine C to obtain the C70.

[Claim 10]

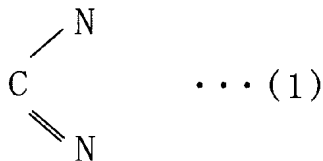
The method of fullerene separation according to claim 9, wherein the dissociation of the second complex is carried out by bringing the second complex into contact with an acid.

[Claim 11]

The method of fullerene separation according to any one of claims 1 to 10, wherein the corresponding amines A to C each have a substructure in which the two nitrogen atoms are bonded through one atom.

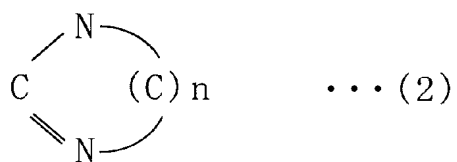
[Claim 12]

The method of fullerene separation according to claim 11, wherein each of the amines having the substructure in which the two nitrogen atoms are bonded has an amidine structure represented by a formula (1).



[Claim 13]

The method of fullerene separation according to claim 12, wherein each of the amines having the amidine structure has a cyclic amidine structure represented by a formula (2).



(n is an integer of 2 or more.)

[Claim 14]

The method of fullerene separation according to claim 13, wherein each of the amines having the cyclic amidine structure is any one of 1,8-diazabicyclo[5.4.0]undec-7-ene and 1,5-diazabicyclo[4.3.0]non-5-ene.

[Claim 15]

A complex comprising a fullerene and an amine having an amidine structure.

[Claim 16]

The complex according to claim 15, wherein the fullerene has 70 or more carbon atoms.

[Claim 17]

The complex according to claim 15 or 16, wherein the amine is any one of 1,8-diazabicyclo[5.4.0]undec-7-ene and 1,5-diazabicyclo[4.3.0]non-5-ene.

[DOCUMENT NAME] DESCRIPTION

[TITLE OF THE INVENTION]

METHOD OF FULLERENE SEPARATION AND COMPLEX CONTAINING FULLERENE

[TECHNICAL FIELD]

[0001]

The present invention relates to a method of fullerene separation and to a complex of a fullerene and an amine.

[BACKGROUND ART]

[0002]

Fullerenes referred to as C60 and C70, carbon clusters having a closed-shell structure, have been recently proposed as new carbon materials, for example, as shown in Patent Document 1. Since these materials are expected to show special properties because of their unique molecular structures, research on their properties and development of use has been increasingly made, and fullerenes are expected to be used in fields of, e.g., diamond coatings, battery materials, paints, heat insulating materials, antifrictions, pharmaceuticals, and cosmetics.

[0003]

As a method for producing fullerenes, a method has been proposed in which a carbon compound is burned to produce fullerenes, for example, as shown in Patent Document 2. Also, another method has been proposed in which an aromatic hydrocarbon such as benzene and an oxygen-containing gas are introduced into a reactor and subjected to incomplete combustion under reduced pressure to produce fullerenes.

[0004]

Fullerene-containing soot obtained by a combustion method etc. contains a fullerene mixture having any two or more of C60, C70 and higher fullerenes having 70 or more carbon atoms (C76, C78, C82, C84, C90, C96, C120, etc.), and a soot residue (e.g., polycyclic aromatic hydrocarbons such as acenaphthylene, fluorene, phenanthrene, pyrene, benzo[b]fluorene, benzo[c]phenanthrene, benzo[a]anthracene, triphenylene, and benzopyrene, carbon having a graphite structure, hydrocarbons having a graphite structure as a skeleton, and carbonaceous polymers such as carbon black). A solvent extraction method has also been known in which the soot is brought into contact with a solvent in which the fullerenes are soluble to dissolve the

fullerenes in the solvent, and the soot residue insoluble in the solvent is removed therefrom to obtain the fullerene mixture.

[0005]

Moreover, as a method for separation of a specific fullerene from the fullerene mixture, a separation method using a column filled with a separating agent such as activated carbon has been known. Another method has been known in which a host compound such as a calixarene or a cyclic phenol sulfide (a calixarene having a sulfur atom) is brought into contact with a specific fullerene (a guest compound) to form an inclusion compound, thereby separating the specific fullerene from fullerenes not included in the inclusion compound (See Patent Document 3 and 4, for example).

[0006]

[PATENT DOCUMENT 1] Japanese Patent No. 2802324

[PATENT DOCUMENT 2] Published Japanese Translation of PCT International Application No. H06-507879

[PATENT DOCUMENT 3] Japanese Patent No. 2654918

[PATENT DOCUMENT 4] Published Japanese Patent Application No. 11-240705

[DISCLOSURE OF THE INVENTION]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

[0007]

However, the separation of a specific fullerene using chromatography requires a great amount of a solvent and is disadvantageous in that the fullerene that interacts strongly with the separating agent is adsorbed by the separating agent, which inhibits recovery of the fullerene. Moreover, although the separation of the specific fullerene using the host compound requires a relatively small amount of the solvent used, the calixarene used as the host compound is a highly designed compound and thus expensive, thereby increasing the cost for separation of the specific fullerene. Another disadvantage is complexity of the operation since change in solvent system is required to separate the specific fullerene and the host compound from the synthesized inclusion compound.

[0008]

The present invention has been made in view of the above problems and aims to provide a

method of fullerene separation by which a specific fullerene is separated from a fullerene mixture with ease and at a low cost, and to provide a complex containing a fullerene.

[MEANS FOR SOLVING THE PROBLEMS]

[0009]

For attaining the above object, a method of fullerene separation according to claim 1 comprises the steps of: bringing a fullerene mixture into contact with an amine A in a solvent to form a complex of a specific fullerene contained in the fullerene mixture with the amine A, the fullerene mixture comprising any two or more of C60, C70 and higher fullerenes having 70 or more carbon atoms, the amine A having two or more nitrogen atoms; and separating the complex from a solution in which fullerenes not forming the complex are dissolved.

[0010]

In the method of fullerene separation according to claim 1, soot including the fullerene mixture comprising any two or more of C60, C70, and higher fullerenes having 70 or more carbon atoms can be produced by such as: (1) an arc-discharge method in which electrodes made of a carbonaceous material such as graphite are used as starting material and arc discharge is applied between the electrodes to evaporate the material; (2) a resistance heating method in which a carbonaceous material is vaporized by application of a high current; (3) a laser vaporization method in which a carbonaceous material is vaporized by irradiation of a pulsed laser having a high energy density; or (4) a combustion method in which organic matter such as benzene is subjected to incomplete combustion.

[0011]

The soot containing fullerenes produced by these methods further contains, besides the fullerenes, a polycyclic aromatic hydrocarbon such as acenaphthylene, fluorene, phenanthrene, pyrene, benzo[b]fluorene, benzo[c]phenanthrene, benzo[a]anthracene, triphenylene, and benzopyrene, carbon having a graphite structure, a hydrocarbon having a graphite structure as a skeleton, and a carbonaceous polymer such as carbon black.

[0012]

Accordingly, a fullerene-enriched material prepared by partly removing graphite, carbon black, and the like from the soot is preferred as the fullerene mixture, and a fullerene-enriched material composed of only fullerenes prepared by entirely removing graphite, carbon black, and the like



from the soot is more preferred. The fullerene-enriched material is obtained by concentrating fullerenes from the soot by various methods, and the methods are not particularly limited. The fullerene-enriched material includes, e.g., a fullerene sublimate obtained from the soot by a sublimation method, a fullerene-containing residue produced by evaporating to dryness a fullerene solution obtained by a solvent extraction method, a fullerene-containing solid obtained by subjecting the soot to column chromatographic separation, and a mixture thereof.

[0013]

A solvent in which fullerenes are soluble is used, e.g., an aromatic hydrocarbon, an aliphatic hydrocarbon and a chlorinated hydrocarbon, which may be cyclic or acyclic, and one or more of these solvents may be used in combination at any ratio.

[0014]

The aromatic hydrocarbon is any hydrocarbon compound having at least one benzene nucleus in a molecule, e.g., an alkylbenzene such as benzene, toluene, xylene, ethylbenzene, n-propylbenzene, isopropylbenzene, n-butylbenzene, sec-butylbenzene, tert-butylbenzene, 1,2,3-trimethylbenzene, 1,2,4-trimethylbenzene, 1,3,5-trimethylbenzene, 1,2,3,4-tetramethylbenzene, 1,2,3,5-tetramethylbenzene, diethylbenzene, and cymene; an alkylnaphthalene such as 1-methylnaphthalene and 2-methylnaphthalene; and tetralin.

[0015]

The aliphatic hydrocarbon may be either cyclic or acyclic. The cycloaliphatic hydrocarbon includes monocyclic aliphatic hydrocarbons such as cyclopentane, cyclohexane, cycloheptane, cyclooctane, and derivatives thereof such as methylcyclopentane, ethylcyclopentane, methylcyclohexane, ethylcyclohexane, 1,2-dimethylcyclohexane, 1,3-dimethylcyclohexane, 1,4-dimethylcyclohexane, isopropylcyclohexane, n-propylcyclohexane, tert-butylcyclohexane, n-butylcyclohexane, isobutylcyclohexane, 1,2,4-trimethylcyclohexane, and 1,3,5-trimethylcyclohexane. The cycloaliphatic hydrocarbon further includes polycyclic aliphatic hydrocarbons such as decalin. The acyclic aliphatic hydrocarbons include n-pentane, n-hexane, n-heptane, n-octane, isooctane, n-nonane, n-decane, n-dodecane, n-tetradecane, etc.

[0016]

Furthermore, the chlorinated hydrocarbon includes such as dichloromethane, chloroform, carbon tetrachloride, trichloroethylene, tetrachloroethylene, 1,2-dichloroethane,

1,1,2,2-tetrachloroethane, chlorobenzene, dichlorobenzene, and 1-chloronaphthalene.

As the solvent, ketone having 6 or more carbon atoms, ester having 6 or more carbon atoms, ether having 6 or more carbon atoms, carbon disulfide, etc. may be used.

[0017]

Among these solvents, from an industrial point of view, solvents that are liquid at room temperature and have boiling points of 100 to 300°C, especially 120 to 250°C, are preferred. Specifically, for example, it is preferable to use an alkylbenzene such as toluene, xylene, mechisylene, 1-methylnaphthalene, 1,2,3,5-tetramethylbenzene, and 1,2,4-trimethylbenzene, and/or an aromatic hydrocarbon such as naphthalene derivatives of tetralin. These solvents may be used alone, or two or more of these solvents may be used in combination as a mixed solvent.

[0018]

As the amine, any amine containing two or more nitrogen atoms and capable of forming a complex with the specific fullerene is used. The amine is either lipid-soluble or water-soluble.

[0019]

The lipid-soluble amine includes 1,8-diazabicyclo[5.4.0]undec-7-ene (hereafter also referred to as DBU), 1,5-diazabicyclo[4.3.0]non-5-ene (hereafter also referred to as DBN), 1,1,3,3-tetramethylguanidine (hereafter also referred to as TMG), 2-methyl-2-imidazoline (hereafter also referred to as IDN), 1,2-dimethyl-1,4,5,6-tetrahydropyrimidine, 1-methyl-2-imidazoline, 2-alkylamidine (e.g., alkyl groups include such as methyl groups and ethyl groups, the same hereunder), tetrakis(dimethylamino)ethylene, and 1-alkyl-1,2,3-triazoline.

[0020]

It would appear that the water-soluble amine includes, for example, 2-aminopyridine, and guanidine. The amine tends to form a complex preferentially with the higher fullerenes having 70 or more carbon atoms and stronger electron-accepting property.

[0021]

The amine can be added as follows. A liquid, lipid-soluble amine can be added as it is or may be added after being diluted with a solvent. A solid, lipid-soluble amine is preferably added after it is dissolved in a solvent which is capable of dissolving the amine and miscible with a solvent in which fullerenes are dissolved. Generally, the water-soluble amine is hardly miscible with a

solvent that dissolves fullerenes such as an aromatic hydrocarbon. Therefore, it is preferable that the water-soluble amine is dissolved in a polar solvent such as water so that the amine contacts with the solvent in which fullerenes are dissolved in a two-layer system.

[0022]

In any method of adding the amine, it is preferable to stir a fullerene solution at a proper speed. A preferred temperature for dripping the amine is in a range of  $-50$  to  $100^{\circ}\text{C}$ , and especially a temperature of  $-20$  to  $50^{\circ}\text{C}$  increases formation speed of the complex, and is thus more preferred. Amount of the amine to be dripped depends on a fullerene content to be separated, but in general, the amount is preferably 2 to 50 molar equivalents of fullerenes to be separated. After completion of the dripping, it is important to mature the fullerene solution until the complex is formed sufficiently.

[0023]

Next, the formed complex is separated from the fullerene solution. The complex is generally insoluble in solvents that dissolve fullerenes. Therefore, it is preferable to use a method such as filtration or decantation for the separation. Moreover, when the formed complex is soluble in the solvent, the complex can be separated from the fullerenes not forming the complex by crystallization etc.

[0024]

Fullerenes can be recovered from the solution in which fullerenes not forming the complex are dissolved. When the solution contains an excessive amount of the amine, the amine can be removed from the solution by addition of an organic acid to precipitate the amine as a salt, or by mixing the solution with an acid aqueous solution or water to remove the amine into a water layer. In the solution from which the amine has been removed, only fullerenes not forming the complex are dissolved. The solution may be used in a subsequent reaction as it is, or the fullerenes may be extracted therefrom as a solid by solvent elimination, crystallization, sublimation or any combination of these methods.

[0025]

Claim 2 provides a method of fullerene separation according to claim 1, wherein the complex is insoluble in the solvent.

In the method in claim 2, the complex forms a precipitate in the solvent, thus the complex can

be separated from a solution in which fullerenes not forming the complex are dissolved using a method such as filtration or decantation.

[0026]

Claim 3 provides a method of fullerene separation according to claims 1 and 2, wherein the complex is dissociated into the specific fullerene and the amine A to obtain the specific fullerene.

In the method in claim 3, the complex is dissociated into the specific fullerene and the amine by addition of a substance having stronger interaction with the amine than with the specific fullerene, particularly an acid such as an organic acid or inorganic acid. The complex can also be dissociated into the fullerene and the amine by chromatography having a stationary phase that strongly interacts with an amine (or amines) in the amine.

[0027]

Claim 4 provides a method of fullerene separation according to claim 3, wherein the dissociation of the complex is carried out by bringing the complex into contact with an acid.

In the method in claim 4, the complex is suspended in a solvent capable of dissolving the fullerenes. Subsequently, while the suspension is stirred well, the acid, for example, an organic acid such as acetic acid, trifluoroacetic acid, or methanesulfonic acid, or an inorganic acid such as sulfuric acid, hydrochloric acid, or phosphoric acid is added to turn the amine into a salt with the acid, thereby separating the fullerenes and making the fullerenes to be in a solution state. By separating the salt by, e.g., water washing or filtration, a solution of the specific fullerene and the salt of the amine with the acid are obtained. This solution can be used as it is for a reaction etc., or solid fullerenes can be extracted therefrom by a method such as solvent elimination, crystallization, sublimation, or any combination thereof.

[0028]

By the method in claims 1 to 4, the specific fullerene can be obtained at a high purity. Moreover, repeating all of or part of the above procedures is effective for further enhancement of fullerene purity. Also, executing the method of the present invention in combination with any one or more of the techniques of chromatography, crystallization, sublimation, inclusion, etc., which are conventionally used as fullerene separation methods, is also effective for enhancement of fullerene purity.

[0029]

For attaining the above object, a method of fullerene separation in claim 5 comprises: a first process of bringing a fullerene mixture comprising C60, C70 and higher fullerenes having 70 or more carbon atoms into contact with an amine B having two or more nitrogen atoms in a solvent to generate a first complex formed by the higher fullerenes and the amine B; a second process of separating the first complex from a first solution in which the C60 and the C70 are dissolved; a third process of bringing the first solution into contact with an amine C having two or more nitrogen atoms to obtain a second complex formed by the C70 and the amine C; and a fourth process of separating the second complex from a second solution in which the C60 is dissolved.

[0030]

In the method in claim 5, the above-mentioned fullerene mixture, amine, and solvent can be used, and the above-mentioned method of adding the solvent can be done. The formed first and the second complexes are generally insoluble in solvents that dissolve fullerenes, and hence it is preferable to use a method such as filtration or decantation for separation of these complexes. Moreover, when the formed complexes are soluble in the solvent, the complexes can be separated from the fullerenes not forming the complexes by crystallization etc.

[0031]

Although the C60 can be recovered from the second solution, when the second solution contains an excessive amount of the amine, it is preferable to remove the amine. As a method for removing the amine, there are, for example, a method in which an organic acid is added to the solution to generate and precipitate a salt of the amine with the organic acid, and a method in which the solution is mixed with an acid aqueous solution or water to remove the amine into a water layer. The solution from which the amine has been removed only contains C60, and the solution can be used in a subsequent reaction as it is, or solid C60 can be extracted therefrom by a method of solvent elimination, crystallization, sublimation, or any combination of these methods.

[0032]

Claim 6 provides a method of fullerene separation according to claim 5, wherein the first and the second complexes are insoluble in the solvent.

In the method in claim 6, the first and the second complexes form precipitates in the solvent,

thus the complexes can be separated from a solution in which fullerenes not forming the complexes are dissolved by a method of filtration, decantation or the like.

[0033]

Claim 7 provides a method of fullerene separation according to claim 6, wherein the first complex is dissociated into the higher fullerenes and the amine B to obtain the higher fullerenes. In the method in claim 7, it is preferable that a substance having stronger interaction with the amine than with the higher fullerenes, especially an acid such as an organic or inorganic acid, is added to dissociate the first complex into the higher fullerenes and the amine. The first complex may also be dissociated by chromatography having a stationary phase that strongly interacts with an amine (amines) in the amine.

[0034]

Claim 8 provides a method of fullerene separation according to claim 7, wherein the dissociation of the first complex is carried out by bringing the first complex into contact with an acid.

In the method in claim 8, the first complex is suspended in a solvent capable of dissolving the fullerenes. Subsequently, while the resultant solution is stirred well, the acid, e.g., an organic acid such as acetic acid, trifluoroacetic acid, or methanesulfonic acid, or an inorganic acid such as sulfuric acid, hydrochloric acid, or phosphoric acid is added to form a salt of the amine and the acid, thereby making the fullerenes to be in a solution state by dissociation. By separating the salt by water washing, filtration or the like, a solution of a specific fullerene having strong interaction with the amine can be obtained. This solution can be used as it is in a subsequent reaction, or solid fullerenes can be extracted therefrom by a method such as solvent elimination, crystallization, sublimation, or any combination of these methods.

[0035]

Claim 9 provides a method of fullerene separation according to claims 5 to 8, wherein the second complex is dissociated into the C70 and the amine C to obtain the C70.

In the method in claim 9, it is preferable that the second complex is dissociated into the C70 and the amine by addition of a substance having stronger interaction with the amine than with the C70, specifically an acid such as an organic acid or an inorganic acid. The second complex can also be dissociated by chromatography having a stationary phase that strongly interacts with an

amine (amines) in the amine.

[0036]

Claim 10 provides a method of fullerene separation according to claim 9, wherein the dissociation of the second complex is carried out by bringing the second complex into contact with an acid.

In the method in claim 10, the second complex is suspended in a solvent capable of dissolving fullerenes. Subsequently, while the resultant solution is stirred well, the acid e.g., an organic acid such as acetic acid, trifluoroacetic acid, or methanesulfonic acid, or an inorganic acid such as sulfuric acid, hydrochloric acid, or phosphoric acid is added to form a salt of the amine and the acid, thereby making the fullerene to be in a solution state by dissociation. By separating the salt by water washing, filtration or the like, a solution of a specific fullerene having strong interaction with the amine can be obtained. This solution can be used as it is in a subsequent reaction, or solid fullerene can be extracted therefrom by a method such as solvent elimination, crystallization, sublimation, or any combination of these methods.

[0037]

Claim 11 provides a method of fullerene separation according to claims 1 to 10, wherein the corresponding amines A to C each have a substructure in which the two nitrogen atoms are bonded through one atom.

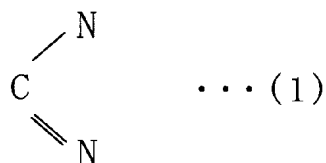
In the method in claim 11, each of the amines has a substructure in which the two nitrogen atoms are bonded through one atom of carbon, nitrogen or the like. The amines include, for example, tetrakis(dimethylamino)ethylene and 1-alkyl-1,2,3-triazoline.

[0038]

Claim 12 provides a method of fullerene separation according to claim 11, wherein each of the amines having the substructure in which the two nitrogen atoms are bonded has an amidine structure represented by a formula (1).

[0039]

[Chemical Formula 1]



[0040]

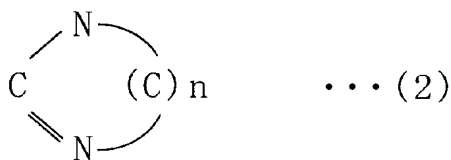
In the method in claim 12, the amines having the amidine structure include, e.g., TMG, IDN, DBU, DBN, 1,2-dimethyl-1,4,5,6-tetrahydropyrimidine, 1-methyl-2-imidazoline, 2-alkylamidine, 2-aminopyridine, and guanidine.

[0041]

Claim 13 provides a method of fullerene separation according to claim 12, wherein each of the amines having the amidine structure has a cyclic amidine structure represented by a formula (2).

[0042]

[Chemical Formula 2]



(n is an integer of 2 or more.)

[0043]

In the method in claim 13, the amines having the cyclic amidine structure include IDN, DBU, DBN, 1,2-dimethyl-1,4,5,6-tetrahydropyrimidine, 1-methyl-2-imidazoline, and 2-aminopyridine. For example, when a complex of C<sub>60</sub> with DBU, a complex of C<sub>70</sub> with DBU, and a complex of a higher fullerene with DBU are formed, each of the complexes is formed by one or two coordinates of DBU and one molecule of fullerene as shown in a formula (3). (In the formula (3), "Fullerene" is a generic term to represent C<sub>60</sub>, C<sub>70</sub> and higher fullerenes)

Fullerene·(DBU)<sub>n</sub>    ⋯ (3)

(n=1-2)

[0044]

Claim 14 provides a method of fullerene separation according to claim 13, wherein each of the amines having the cyclic amidine structure is any one of 1,8-diazabicyclo[5.4.0]undec-7-ene



and 1,5-diazabicyclo[4.3.0]non-5-ene.

[0045]

For attaining the above object, a complex in claim 15 comprises a fullerene and an amine having an amidine structure.

As for the complex in claim 15, the amine having the amidine structure includes, e.g., straight-chain TMG, 2-alkylamidine, and guanidine; monocyclic IDN, 1,2-dimethyl-1,4,5,6-tetrahydropyrimidine, 1-methyl-2-imidazoline, and 2-aminopyridine; and polycyclic DBU and DBN.

[0046]

As for the complex in claim 16 according to claim 15, the fullerene has 70 or more carbon atoms.

As for the complex in claim 16, the fullerene having 70 or more carbon atoms includes C70, C76, C78, C82, C84, C86, C88, C90, C92, C94, and C96, and also includes derivatives thereof.

[0047]

As for a complex in claim 17 according to claims 15 and 16, the amine is any one of 1,8-diazabicyclo[5.4.0]undec-7-ene and 1,5-diazabicyclo[4.3.0]non-5-ene.

[EFFECT OF THE INVENTION]

[0048]

A method of fullerene separation in claim 1 and claims 2 to 4 and 11 to 14 dependent on claim 1 comprises the steps of: forming a complex of a specific fullerene contained in the fullerene mixture with the amine A, the fullerene mixture comprising any two or more of C60, C70 and higher fullerenes having 70 or more carbon atoms, the amine A having two or more nitrogen atoms; and separating the complex from a solution in which fullerenes not forming the complex are dissolved, by which a specific fullerene and fullerenes not forming the complex can be separated from a fullerene mixture. As a result, a specific fullerene is separated from a fullerene mixture with ease and at a low cost.

[0049]

According to a method of fullerene separation in claim 2, in particular, since the complex is insoluble in the solvent, the complex forms a precipitate in the solvent, and thus the complex can be easily separated.

According to a method of fullerene separation in claim 3, the complex is dissociated into the specific fullerene and the amine A to obtain the specific fullerene.

According to a method of fullerene separation in claim 4, since the dissociation of the complex is carried out by bringing the complex into contact with an acid, a salt of the amine is precipitated with the acid and the specific fullerenes dissolved in the solvent can be obtained.

[0050]

A method of fullerene separation in claim 5 and claims 6 to 14 dependent on claim 5 comprises the steps of: bringing a fullerene mixture comprising C60, C70 and higher fullerenes having 70 or more carbon atoms into contact with an amine B having two or more nitrogen atoms to separate a first complex formed by the higher fullerenes and the amine B; and further bringing the first solution in which the C60 and the C70 are dissolved into contact with an amine C having two or more nitrogen atoms to separate a second complex formed by the C70 and the amine C, thereby obtaining a second solution in which the C60 is dissolved. As a result, C60, C70 and higher fullerenes having 70 or more carbon atoms are individually separated from the fullerene mixture with ease and at a low cost.

[0051]

According to the method of fullerene separation in claim 6, in particular, since the first and second complexes are insoluble in the solvent, the complexes forms a precipitate in the solvent and the complexes can be easily separated.

According to the method of fullerene separation in claim 7, the first complex is dissociated into the higher fullerene and the amine B to obtain the higher fullerene.

According to the method of fullerene separation in claim 8, since the dissociation of the first complex is carried out by bringing the first complex into contact with an acid, a salt of the amine is precipitated with the acid and the higher fullerenes dissolved in the solvent can be obtained.

[0052]

According to the method of fullerene separation in claim 9, the second complex is dissociated into the C70 and the amine C to obtain the C70.

According to the method of fullerene separation in claim 10, since the dissociation of the second complex is carried out by bringing the second complex into contact with an acid, a salt of the

amine is precipitated with the acid and the C70 dissolved in the solvent can be obtained.

[0053]

According to the method of fullerene separation in claim 11, the amine has a substructure in which the two nitrogen atoms are bonded through one atom, by which the amine can form a complex preferentially with the fullerene.

According to the method of fullerene separation in claim 12, the amine having the substructure in which the two nitrogen atoms are bonded through one atom has an amidine structure, by which the amine can form a complex preferentially with the fullerene.

[0054]

According to the method of fullerene separation in claim 13, the amine having the amidine structure has a cyclic amidine structure, by which the amine can form a complex preferentially with the fullerene.

According to the method of fullerene separation in claim 14, the amine having the cyclic amidine structure is 1,8-diazabicyclo[5.4.0]undec-7-ene or 1,5-diazabicyclo[4.3.0]non-5-ene, by which the amine can form a complex preferentially with the fullerene.

[0055]

The complexes in claims 15 to 17 include a fullerene and an amine having the amidine structure, and thus the complexes can be intermediates for the isolation of the specific fullerene.

In particular, the complex in claim 16 includes a fullerene having 70 or more carbon atoms, and thus the complex can be intermediates for the isolation of the fullerene having 70 or more carbon atoms.

The complex in claim 17 includes an amine being 1,8-diazabicyclo[5.4.0]undec-7-ene or 1,5-diazabicyclo[4.3.0]non-5-ene, and thus the amine can easily form a complex with the fullerenes having 70 or more carbon atoms.

[BEST MODE FOR CARRYING OUT THE INVENTION]

[0056]

Referring to the accompanying drawing, an embodiment of the present invention will be described for a better understanding of the present invention.

FIG. 1 is an explanatory diagram of a fullerene producing apparatus to which a method of fullerene separation according to one embodiment of the present invention is applied.

[0057]

Referring to FIG. 1, a fullerene producing apparatus 10, to which a method of fullerene separation according to one embodiment of the present invention is applied, is explained in process order.

The fullerene producing apparatus 10 separates C60, C70 and higher fullerenes having 70 or more carbon atoms individually from a fullerene mixture comprising the C60, the C70 and the higher fullerenes.

[0058]

(First Process)

The fullerene producing apparatus 10 has a fullerene tank 11 for storing the fullerene mixture. As the fullerene mixture, a solid containing C60, C70 and higher fullerenes having 70 or more carbon atoms is used. The solid is extracted by adding soot obtained by a combustion method etc. to a solvent (e.g., 1,2,4-trimethylbenzene, hereafter referred to as TMB), removing a soot residue in the soot from the solution, and further removing the solvent.

[0059]

The soot used may also be produced by an arc-discharge method, a resistance heating method or a laser vaporization method instead of the combustion method, however, the combustion method is preferred because of highness of fullerene content in the soot (e.g., the soot produced by the combustion method contains 10 to 30 wt.% fullerenes).

[0060]

As the fullerene mixture, a fullerene-enriched material obtained by removing all of or part of graphite and carbon black etc. from the soot may also be used.

The fullerene-enriched material is obtained by concentrating fullerenes from the soot by various methods, and the methods are not particularly limited. The fullerene-enriched material includes, e.g., a fullerene sublimate obtained from the soot by a sublimation method, a fullerene solution obtained by a solvent extraction method, a fullerene-containing solid obtained by subjecting the soot to column chromatographic separation, and a mixture thereof.

[0061]

The apparatus 10 includes a solvent tank 12 for storing a solvent, e.g., TMB, that dissolves the fullerenes. The solvent used in the apparatus 10 includes, besides TMB, solvents in which the

fullerenes are soluble, such as aromatic hydrocarbons, aliphatic hydrocarbons, chlorinated hydrocarbons, which may be cyclic or acyclic. These solvents may be used alone or two or more of these solvents may be used in combination at any ratio.

[0062]

Among these solvents, solvents that are liquid at room temperature and have boiling points of 100 to 300°C, especially 120 to 250°C, are preferred from an industrial point of view. Specifically, for example, it is preferable to use an alkylbenzene such as toluene, xylene, mechisylene, 1-methylnaphthalene, and 1,2,3,5-tetramethylbenzene, and/or an aromatic hydrocarbon such as naphthalene derivatives of tetralin. These solvents may be used alone, or two or more of these solvents may be used in combination as a mixed solvent.

[0063]

The apparatus 10 further includes an amine tank 13 for storing 1,8-diazabicyclo[5.4.0]undec-7-ene (liquid, hereafter also referred to as DBU), an example of an amine that easily forms a complex with a specific fullerene (especially higher fullerenes).

[0064]

The amines include, besides DBU, any compound having two or more nitrogen atoms and capable of forming a complex with a specific fullerene, for example, a compound having an amidine structure with a substructure where two nitrogen atoms are bonded through one atom represented by the formula (1), or a cyclic amidine structure represented by the formula (2). Examples of the amines are such as 1,5-diazabicyclo[4.3.0]non-5-ene (hereinafter referred to as DBN), 1,1,3,3-tetramethylguanidine (hereinafter referred to as TMG), 2-methyl-2-imidazoline (hereinafter referred to as IDN), 1,2-dimethyl-1,4,5,6-tetrahydropyrimidine, 1-methyl-2-imidazoline, 2-alkylamidine, guanidine, tetrakis(dimethylamino)ethylene, and 1-alkyl-1,2,3-triazoline.

[0065]

The apparatus 10 includes a first mixing tank 14 in which the fullerene mixture and the DBU are mixed in the TMB to form a first complex of the higher fullerenes contained in the fullerene mixture with the DBU. The first mixing tank 14 is provided with a temperature controller (not shown) capable of adjusting the temperature inside the first mixing tank 14 in a range of -50 to 100°C and an agitating blade for efficiently mixing the fullerene mixture with the DBU. The

pressure in the first mixing tank 14 during the mixing is not specifically limited and the mixing is carried out at normal pressures.

[0066]

While the agitating blade of the first mixing tank 14 is rotated at an appropriate speed, the DBU is gradually supplied from the amine tank 13 by dripping. A temperature preferable for the dripping is, e.g.,  $-50$  to  $100^{\circ}\text{C}$ . Especially a temperature of  $-20$  to  $50^{\circ}\text{C}$  accelerates production speed of the complex, and is thus preferable. Amount of the drip depends on a fullerene content to be separated, but in general, the amount is preferably 2 to 50 molar equivalents of fullerenes to be separated. After completion of the dripping, it is preferable to stir the resultant solution until the complex is formed sufficiently.

[0067]

In the first mixing tank 14, mainly the higher fullerenes contained in the fullerene mixture and the DBU form the first complex represented by a formula (4).

Higher fullerene  $\cdot (\text{DBU})_n \cdots (4)$

( $n=1-2$ )

The produced first complex forms a precipitate in the TMB, thus the first complex can be separated using a method such as filtration or decantation. C60, C70 and DBU not forming the complex are dissolved in the TMB. C60 and C70 also form complexes with the DBU and form precipitates although the amounts thereof are little.

[0068]

(Second Process)

The apparatus 10 includes a separator, e.g., a first continuous pressure filter 15, for separating the first complex from a solution (first solution) in which the C60 and the C70 are dissolved. The separator may be, besides the pressure filter, a vacuum filter or a centrifuge (the same for separators described hereafter). The apparatus 10 includes a first dissociation tank 16 where the first complex separated by the first filter 15 is dissociated into the higher fullerenes and the amine. The first dissociation tank 16 is provided with an agitating blade for efficiently mixing the first complex with trifluoroacetic acid, and a temperature controller not shown.

[0069]

The apparatus 10 has an acid tank 17 for storing an acid, e.g., trifluoroacetic acid that is an

organic acid. The first complex separated by the first filter 15 and the TMB in the solvent tank 12 are supplied into the first dissociation tank 16 to suspend the first complex in the TMB, and then the trifluoroacetic acid is further supplied from the acid tank 17. In the first dissociation tank 16, the first complex and the trifluoroacetic acid are mixed. Since trifluoroacetic acid has stronger interaction with DBU than with higher fullerenes, the first complex is dissociated into higher fullerenes dissolved in the TMB and a salt of the DBU with the trifluoroacetic acid, and the generated salt is precipitated.

[0070]

The apparatus 10 further includes a separator, e.g., a second continuous pressure filter 18, for separating a solution of the higher fullerenes from the salt of the DBU with the trifluoroacetic acid. The apparatus 10 has a first conical ribbon mixer dryer 19. To the first conical ribbon mixer dryer 19, the solution of the higher fullerenes separated by the second filter 18 is supplied, and the solution is dried at a temperature equal to or higher than the boiling point of TMB, e.g., 130°C, and at a pressure of 0.3kPa until the TMB is removed thoroughly (e.g., for 25 hours) to obtain solid higher fullerenes. The removed TMB is supplied into the solvent tank 12 for reuse. Although the first conical ribbon mixer dryer 19 is used for removal of the TMB from the solution of the higher fullerenes, a tray vacuum dryer, a conical dryer or the like may be used (the same for conical ribbon mixer dryers described hereunder).

[0071]

When the solution of the higher fullerenes separated by the second filter 18 contains an excessive amount of the amine that does not form a complex with the higher fullerenes, it is preferable to remove the amine prior to the removal of the TMB by the first conical ribbon mixer dryer 19. The amine may be removed, for example, by adding an organic acid to the solution to precipitate the amine as a salt with the acid, or by mixing the solution with an acid aqueous solution or water to remove the amine into a water layer (hereafter, also the same as to the separation of the C60 and the C70).

[0072]

The solution from which the amine has been removed can be used as it is in a subsequent reaction, or the higher fullerenes can be extracted as a solid by a method such as crystallization, sublimation, or a combination of these methods besides solvent elimination (hereunder, also the

same for C60 and C70).

[0073]

(Third Process)

The apparatus 10 includes a second mixing tank 20 where the C70 contained in the TMB separated by the first filter 15 is made to react with DBU to form a second complex. In the TMB separated by the filter 15, C60 and C70 are dissolved. The second mixing tank 20 is provided with a temperature controller (not shown) capable of adjusting the temperature inside the second mixing tank 20 in a range of  $-50$  to  $100^{\circ}\text{C}$  and an agitating blade for efficiently mixing the C60 and the C70 with the DBU. The pressure in the second mixing tank 20 during the mixing is not specifically limited and the mixing is carried out at normal pressures.

[0074]

While the agitating blade of the second mixing tank 20 is rotated at a proper speed, the DBU is supplied by being gradually dripped from the amine tank 13. The temperature in the second mixing tank 20 and the dripping speed of the amine are the same as those at the time of forming the first complex in the first mixing tank 14.

[0075]

In the second mixing tank 20, mainly the C70 and the DBU form the second complex represented by a formula (5).



( $n=1-2$ )

The produced second complex forms a precipitate in the TMB, thus the second complex can be separated using a method such as filtration or decantation. C60 and DBU not forming the complex are dissolved in the TMB. C60 also forms a complex with the DBU and forms a precipitate although the amount thereof is little.

[0076]

(Fourth Process)

The apparatus 10 includes a separator, e.g., a third continuous pressure filter 21, for separating the second complex from a solution (a second solution) in which the C60 is dissolved. The apparatus 10 further includes a second dissociation tank 22 where the second complex separated by the third filter 21 is dissociated into the C70 and the amine. The second dissociation tank 22



is provided with an agitating blade for efficiently mixing the second complex with trifluoroacetic acid supplied from the acid tank 17 and a temperature controller not shown.

[0077]

The second complex separated by the third filter 21 and the TMB in the solvent tank 12 are supplied into the second dissociation tank 22, the second complex is suspended in the TMB, and subsequently trifluoroacetic acid is supplied from the acid tank 17 to the tank 22. In the second dissociation tank 22, the second complex and the trifluoroacetic acid are mixed. Since trifluoroacetic acid has stronger interaction with DBU than with C70, the second complex is dissociated into C70 dissolved in the TMB and a salt of the DBU with the trifluoroacetic acid, and the generated salt is precipitated.

[0078]

The apparatus 10 has a separator, e.g., a fourth continuous pressure filter 23, for separating a solution of C70 from the salt of the DBU and the trifluoroacetic acid. The apparatus 10 also has a second conical ribbon mixer dryer 24. To the second conical ribbon mixer dryer 24, the solution of C70 separated by the fourth filter 23 is supplied, and the solution is dried at a temperature equal to or higher than the boiling point of TMB, e.g., 130°C, and at a pressure of 0.3kPa until the TMB is removed thoroughly (e.g., for 25 hours) to obtain solid C70. The removed TMB is supplied into the solvent tank 12 for reuse.

[0079]

The apparatus 10 includes a third conical ribbon mixer dryer 25. In the third conical ribbon mixer dryer 25, a solution of C60 separated by the third filter 21 is dried at a temperature equal to or higher than the boiling point of TMB, e.g., 130°C, and at a pressure of 0.3kPa until the TMB is removed thoroughly (e.g., for 25 hours) to obtain a solid of C60. The removed TMB is supplied to the solvent tank 12 for reuse.

[0080]

By the above-described procedures, the specific fullerene(s) can be obtained at high purity. However, repeating the procedures entirely or partly for multiple times is effective for further enhancement of the purity. Moreover, a combination of the procedures and any one or more of techniques such as chromatography, crystallization, sublimation, and inclusion (complex formation), which are conventional methods of fullerene separation, is also effective to enhance

the purity of the fullerenes.

[EMBODIMENT]

[0081]

(Experiment 1: Separation of C60, C70 and higher fullerenes from the fullerene mixture using DBU)

A fullerene mixture in an amount of 0.56g (having a composition of C60: 64 wt.%, C70: 23 wt.%, higher fullerenes: 13 wt.%, the same hereunder) was dissolved in 19.4g of TMB, and this solution was cooled to 0°C. Here, 0.56g of the fullerene mixture contains 0.36g of C60, 0.13g of C70, and 0.07g of higher fullerenes. Subsequently, 0.20g of DBU was gradually added taking one minute. The solution was stirred for 1.5 hours, whereby a precipitate having a sedimentation property, i.e., the first complex, was formed.

[0082]

The solution was filtrated to obtain the first complex and the first solution. The first complex was suspended in 100g of TMB and 0.50g of trifluoroacetic acid was added thereto. This solution was heated to 40°C, and stirred for 2 hours, whereby the higher fullerenes and a precipitate of a salt of the DBU with the trifluoroacetic acid were obtained. The precipitate was separated by filtration. The obtained filtrate was washed with 10.0g of demineralized water (ion-exchange water) until the wash water was neutral (e.g., washed for three times).

[0083]

After the washing, the solution was analyzed with HPLC, and 0.003g of fullerenes mainly comprising the higher fullerenes was obtained. The obtained TMB solution contained 60 wt.% higher fullerenes, and the recovery rate of higher fullerenes from the fullerene mixture was 3 wt.%. Furthermore, solid higher fullerenes can be obtained by removing TMB from the TMB solution of the higher fullerenes.

[0084]

The obtained first solution was kept at 0°C, and 0.40g of DBU was gradually added thereto for one minute. This solution was stirred for one hour, whereby a precipitate having a sedimentation property, i.e., the second complex, was formed. This solution was filtrated to obtain the second complex and the second solution.

[0085]

The second complex was suspended in 100g of TMB and 0.05g of trifluoroacetic acid was added thereto. This solution was heated to 40°C, and stirred for 2 hours, whereby C70 and a precipitate of a salt of the DBU and the trifluoroacetic acid were obtained. The precipitate was separated by filtration. The obtained filtrate was washed with 10.0g of demineralized water until the wash water was neutral (e.g., washed for three times).

[0086]

After the washing, this solution was analyzed with HPLC, and 0.009g of fullerenes mainly comprising C70 was obtained. This obtained TMB solution contained 64 wt.% C70, and the recovery rate of C70 from the fullerene mixture was 4 wt.%. Furthermore, solid C70 can be obtained by removing TMB from the TMB solution of C70.

[0087]

The second solution was washed with 10.0g of demineralized water until the wash water was neutral (e.g., washed for three times). After the washing, this TMB solution was analyzed with HPLC, and 0.27g of fullerenes mainly comprising C60 was obtained. The obtained TMB solution contained 99 wt.% C60, and the recovery rate of C60 from the fullerene mixture was 74 wt.%. Furthermore, solid C60 can be obtained by removing TMB from the TMB solution of C60.

[0088]

(Experiment 2: Separation of C60 from the fullerene mixture using DBN)

A fullerene mixture (0.34g) was dissolved in 19.7g of TMB, and this solution was cooled to 0°C. Here, 0.34g of the fullerene mixture contained 0.22g of C60, 0.08g of C70, and 0.04g of higher fullerenes. Subsequently, 0.28g of DBN was gradually added taking one minute. This solution was stirred for 5 hours, whereby a complex having a sedimentation property was obtained, and the complex was separated by filtration. This filtrate was washed with 20.0g of demineralized water until the wash water was neutral (e.g., washed for three times). After the washing, this TMB solution was analyzed with HPLC, and 0.18g of fullerenes mainly comprising C60 was obtained. This obtained TMB solution contained 96 wt.% C60, and the recovery rate of C60 from the fullerene mixture was 82 wt.%. Furthermore, solid C60 can be obtained by removing TMB from the TMB solution of C60.

[0089]

(Experiment 3: Separation of C60 from the fullerene mixture using IDN)

A fullerene mixture (0.34g) was dissolved in 19.7g of TMB, and this solution was cooled to 0°C. Subsequently, 0.30g of IDN was added gradually taking one minute. This solution was stirred for 3 hours, whereby a complex having a sedimentation property was formed, and the complex was separated by filtration. This filtrate was washed with 20.0g of demineralized water until the wash water was neutral (e.g., washed for three times.) After the washing, this TMB solution was analyzed with HPLC, and 0.13g of fullerenes mainly comprising C60 was obtained. This obtained TMB solution contained 69 wt.% C60, and the recovery rate of C60 from the fullerene mixture was 60 wt.%. Furthermore, solid C60 can be obtained by removing TMB from the TMB solution of C60.

[0090]

(Experiment 4: Separation of C60 from the fullerene mixture using TMG)

A fullerene mixture (0.34g) was dissolved in 19.7g of TMB, and this solution was cooled to 0°C. Subsequently, 0.26g of TMG was added gradually taking one minute. This solution was stirred for 5 hours, whereby a complex having a sedimentation property was formed, and the complex was separated by filtration. This filtrate was washed with 20.0g of demineralized water until the wash water was neutral (e.g., washed for three times). After the washing, this TMB solution was analyzed with HPLC, and 0.21g of fullerenes mainly comprising C60 was obtained. This obtained TMB solution contained 69 wt.% C60, and the recovery rate of C60 from the fullerene mixture was 96 wt.%. Furthermore, solid C60 can be obtained by removing TMB from the TMB solution of C60.

[0091]

(Experiment 5: Complex of C70 with DBU)

C70 (0.05g) was dissolved in 3.0g of TMB, and this TMB solution was cooled to 0°C. Subsequently, 0.05g of DBU was added gradually taking one minute. This TMB solution was stirred for 5 hours, whereby a complex was formed. After the TMB solution was separated by filtration, the filtered residual was vacuum dried, and 0.03g of the complex of the C70 and the DBU in a solid state was obtained. By elemental analysis, the solid complex contained 86.3 wt.% of C; 2.0 wt.% of H; and 2.8 wt.% of N. Here, calculated from the ratio of C to N, the number of DBU attached to C70 was 1.1.

[0092]

(Experiment 6: Complex of C60 with DBU)

C60 (0.05g) was dissolved in 3.0g of TMB, and this TMB solution was cooled to 0°C. Subsequently, 0.05g of DBU was added gradually taking one minute. This TMB solution was stirred for 5 hours, whereby a complex was formed. The TMB solution was separated by filtration, and then the filtered residual was vacuum dried, whereby 0.02g of complex of the C60 and the DBU in a solid state was obtained. By elemental analysis, the solid complex contained: 84.1 wt.% of C; 2.8 wt.% of H; and 4.4 wt.% of N. Here, calculated from the ratio of C to N, the number of DBU attached to C60 was 1.7.

[0093]

The present invention is not limited to the above-described embodiment or experiments, and various modifications may be made without departing from the scope or spirit of the present invention. For instance, the present invention includes a case where the method of fullerene separation and the complex comprising a fullerene according to the present invention comprise a part of or all of the above respective embodiments and experiments.

[0094]

For instance, in the method of fullerene separation of the above embodiment, when the complex of the fullerene and the amine is soluble in the solvent, i.e., when the complex does not form a precipitate, crystallization or the like may be employed to separate the complex from fullerenes not forming the complex.

[BRIEF DESCRIPTION OF DRAWINGS]

[0095]

[FIG. 1] FIG. 1 is an explanatory diagram of a fullerene producing apparatus to which a method of fullerene separation according to one embodiment of the present invention is applied.

[DESCRIPTION OF NUMERALS]

[0096]

10: fullerene producing apparatus; 11: fullerene tank; 12: solvent tank; 13: amine tank; 14: first mixing tank; 15: first filter; 16: first dissociation tank; 17: acid tank; 18: second continuous pressure filter; 19: first conical ribbon mixer dryer; 20: second mixing tank; 21: third continuous pressure filter; 22: second dissociation tank; 23: fourth continuous pressure filter; 24: second

conical ribbon mixer dryer; 25: third conical ribbon mixer dryer

[DOCUMENT NAME] ABSTRACT

[ABSTRACT]

[PROBLEM TO BE SOLVED]

The present invention provides a method of fullerene separation by which a specific fullerene is separated from a fullerene mixture with ease and at a low cost, and to provide a complex containing a fullerene.

[SOLUTION]

A fullerene mixture comprising any two or more of C60, C70 and higher fullerenes having 70 or more carbon atoms is brought into contact with an amine having two or more nitrogen atoms, especially an amine having an amidine structure, in a solvent to form a complex of a specific fullerene contained in the fullerene mixture and the amine, and the complex is separated from a solution in which fullerenes not forming the complex are dissolved.

[SELECTED DRAWING] FIG. 1

[DOCUMENT NAME] DRAWING

[Fig. 1]

